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ELECTROMAGNETIC RADIATION PRODUCED IN THE DETONATION OF INDUSTRIAL EXPLOSIVES

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Electromagnetic Radiation Produced in the Detonation of Industrial Explosives

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Makeyevka Scientific Research Institute for Mine Safety

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The electromagnetic radiation which results from the detonation of explosive charges, first discovered by Ivanov (1), is one of the least investigated of the phenomena which accompany the detonation. In the few works devoted to this question, essentially only the fact of the radiation is stated and one or another hypothesis is brought forward to explain the phenomenon. Thus, in the work of Kolsky (2) the appearance of radiation during the explosion is explained by the formation of dipoles, due to the separation of negative and positive ions in the expanding explosion products. The origin of such a separation is the different mobility of ions of unlike polarity. In the works of Koch (3) and Takakura (4) this phenomenon is explained by other causes, of a random nature. They assume that the radiation arises because of the mutual retardation of a group of like charges in turbulent motion. The statistical superposition of radiation from such "single" sources yields the observed electromagnetic

pulse.

The hypotheses in question are in contradiction with certain experimental data and reliably established facts, namely:

as will be shown below, with each explosive is associated a characteristic and reproducible pulse of electromagnetic radiation, which is difficult to explain by the random sources suggested by Koch and Takakura;

Kolsky's hypothesis is based on the assumption that the ionized detonation products consist of positive and negative ions. At the same time, it can be assumed to have been demonstrated (5) that in reality they consist chiefly of positive ions and free electrons.

Considering the shortcomings of the hypotheses in question, several other explanations of this phenomenon suggest themselves to us.

The ionized detonation products consist principally of free electrons and positive ions. These products expand from the center of the explosion to the periphery under the influence of the excess pressure.

Making use of the methods of the kinetic molecular theory of gases, it can be shown that the relative mobility of ions and free electrons in the pressure field is determined by the expression

3

$$\frac{k_u}{k_э} = \sqrt{\frac{m_u}{8 m_э}}, \qquad (1)$$

where $k_и$ is the mobility of the ion;

$k_э$ is the mobility of the electron;

$m_и$ is the mass of the ion;

$m_э$ is the mass of the electron.

From Eq. (1) it follows that the mobility of the ions in the pressure field will be considerably greater than the mobility of the electrons. Consequently, during the expansion of the explosion products a separation of carriers of unlike charges will develop, resulting in the formation of a spatial dipole whose moment changes with time. As is well known, the formation of such a dipole always is accompanied by the emission of electromagnetic radiation. The magnitude of the signal received by an antenna is then determined by the expression

$$A = c \cdot \frac{\partial^2 M}{\partial t^2}, \qquad (2)$$

where M is the dipole moment;

c is a constant factor.

It may be assumed that the cloud of expanding explosion products is approximately symmetric with respect to the axis of the cartridge case, that is, it has the form of a cylinder. We consider an elementary volume dV in such a cylinder. The quantity of charge in this volume, dQ, obviously will be equal to nxqdV, where n is the concentration of particles, x is the degree of ionization, and q is the charge of a single particle.

The separation between the negative and positive charges at the moment of time t will be equal to

$$R = (k_n - k_s) Pt,$$

where P is the average pressure in the cloud of gas at time t.

The dipole moment of the given elementary volume is then defined as

$$dM = (k_n - k_s) Ptnxq dV,$$

and the dipole moment of the entire gas cloud is*

$$M = (k_n - k_s) Ptxq \int n dV;$$
$$\int n dV = N,$$

where N is the total number of molecules in the gas cloud.

Consequently,

$$M = (k_n - k_s) PtxqN. \qquad (3)$$

It is obvious that

$$(k_n - k_s) qN = c;$$
$$M = cPtx; \qquad (4)$$

(c is a constant factor).

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* It must be borne in mind that, at each instant of time, P and x are determined by the corresponding parameters of the expanding cloud of gas.

Thus the dipole moment, and consequently the signal received by the antenna at each instant of time, depends on the degree of

ionization x and the nature of the expansion of the gas, determined by the change of the pressure P.

The change of these quantities with time determines the shape, polarity, and amplitude of the pulse. Other conditions being equal, the greater the value of M, the greater will be the amplitude of the received signal. For this reason, all the factors leading to an increase of M (all other conditions being equal) cause an increase of the signal, A, received by the antenna.

We have conducted an investigation of the pulses of electromagnetic radiation arising from the detonation of the most characteristic industrial explosives. A schematic drawing of the experimental arrangement is shown in Fig. 1.

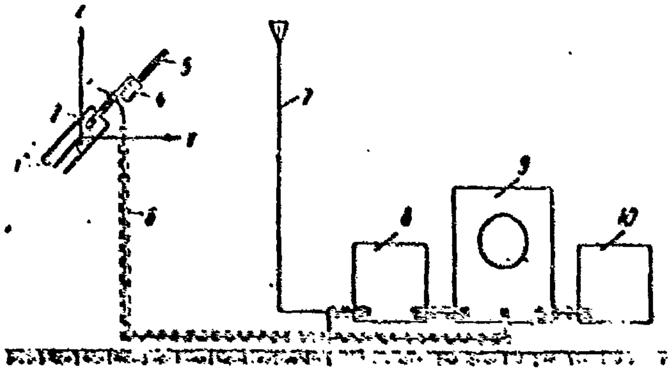

Fig. 1. Schematic drawing of the experimental arrangement for the investigation of electromagnetic radiation produced by the detonation of explosives.

1 - explosive cartridge. 2 - detonating cord. 3 - ionization gauge. 4 - detonating cap. 5 - fuse. 6 - oscillograph triggering cable. 7 - antenna. 8 - cathode follower. 9 - oscillograph OK-17M. 10 - time mark generator.

As a result of conducting these experiments the following facts were established: 1) the emission of electromagnetic energy is connected essentially with the expansion of gaseous products of the detonation; 2) each explosive has a characteristic electromagnetic pulse, reproducible in parallel experiments; 3) for different explosives these pulses differ markedly one from another.

The above statements are illustrated by Fig. 2, which shows the pulses of electromagnetic radiation arising from the detonation of several explosives.

The question arises as to which concrete factors are determined by the peculiarities of the radiation from various types of explosives.

As a result of the investigations conducted, it has been established that the following factors sharply increase the radiation intensity:

1) inclusion in the composition of the explosive of various easily-ionized additives, such as salts of alkali metals, which serve as flash inhibitors in safety explosives. For example, Fig. 3 shows oscillograms of the pulses from the detonation of ammonites No. 6 ZhV (127/13) and No. PZhV-20 (127/8), which differ from one another only in that the composition of the latter includes 20% NaCl. It is well known that the ionization potentials of such substances are 4-5 ev, whereas they amount to 12-13 ev for the other characteristic products of the detonation.

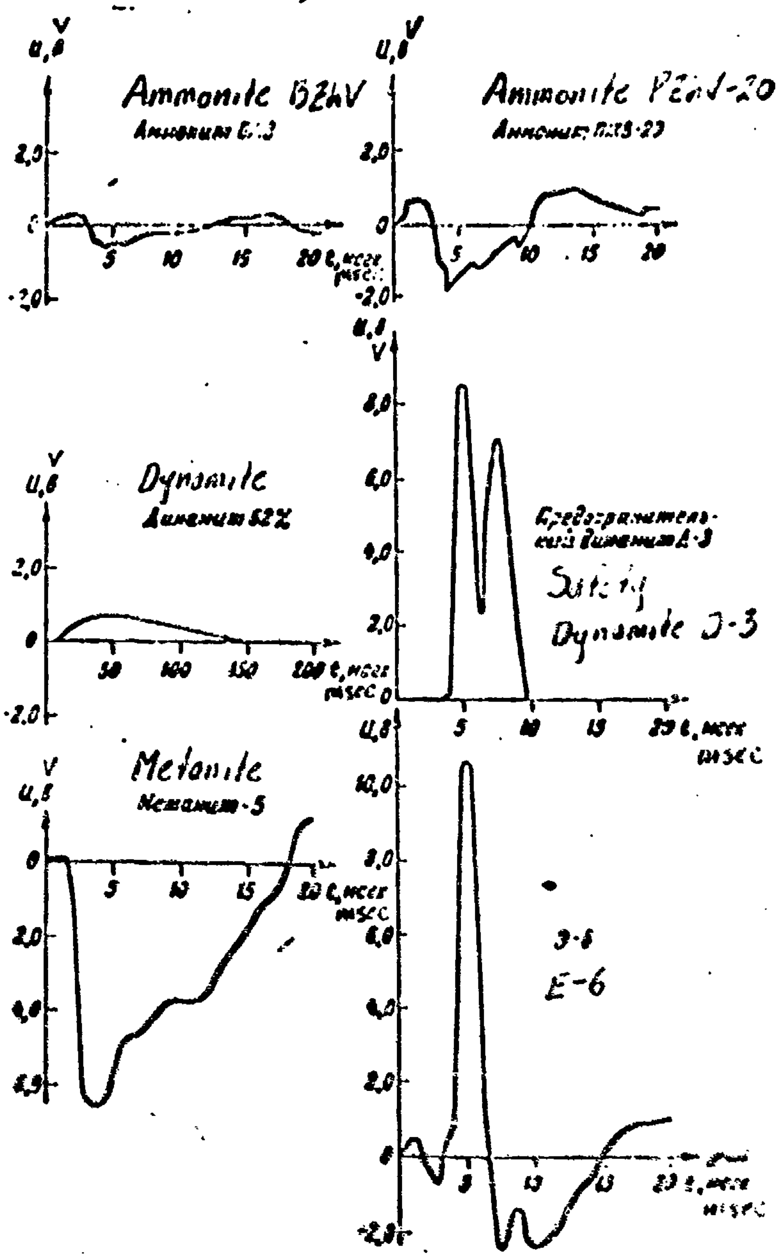

Fig. 2. Electromagnetic pulses from the detonation of various explosives.

For this reason, such additives greatly increase the ion content of the detonation products; this is confirmed by the results of experiments involving the direct determination of the electrical conductivity of the explosion products;

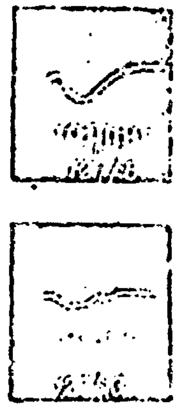

Fig. 3. Influence of sodium chloride on the electromagnetic radiation from an explosion.

2) introduction of various combustible additives into the explosive (for example, aluminum or sawdust). This is illustrated by the oscillograms shown in Fig. 4. Oscillograms 127/9 and 156/11 show the electromagnetic pulses of ammonite No. 6 and a compound which differs from it only by the presence of 5% aluminum powder, and oscillograms 135/14 and 135/18 show pulses of compounds, the second of which differs from the first only in that it contains 3% sawdust. From the oscillograms it is evident that aluminum, as well as sawdust, substantially increases the intensity of the radiation.

We will examine the factors which determine the nature of the established influence of the easily-ionized and combustible additives.

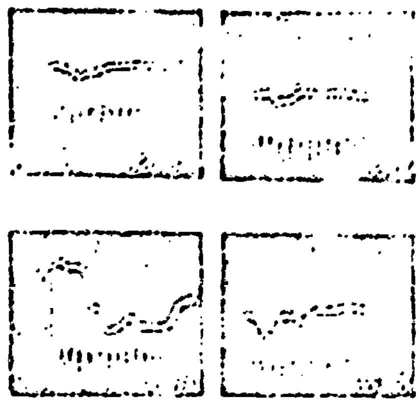

Fig. 4. Influence of combustible additives on the electromagnetic radiation from an explosion.

Introduction of the former leads to a sharp increase of the degree of ionization of the detonation products. For this reason, x increases in Eq. (4) and consequently M also increases. Other conditions being equal, this leads to an increase of the second derivative of M and thus to an increase of the signal received by the antenna. It is probably this effect which explains the presence of a large pulse of radiation from safety explosives of the types E-6 and D-3.

Combustible additives introduced into the explosive, reacting with the detonation products of the explosive components, increase the temperature of these products and, moreover, maintain it for a relatively long period of time (6). As a result, naturally, the ion recombination processes are retarded (x in Eq. (4) increases, which is equivalent to an increase of the space charge in the cloud of expanding explosion products). The latter is a factor which contributes to the increase of the radiation pulse. Furthermore, with increased temperature the ex-

pansion of the explosion products will be more rapid, which also increases the radiation.

It is interesting to note that the various detonative components of mixed explosives do not exert any substantial influence on the nature of the electromagnetic radiation from the explosion. The latter is determined chiefly by certain non-detonative additives included in the composition.

The factors examined above are, so to speak, "internal" in relation to the charge. The character of the radiation is also greatly influenced by the external conditions under which the detonation occurs. In all cases in which certain factors (casings, walls of bore holes, etc.) operate to hinder the expansion of the detonation products, the amplitude of the radiation pulse increases sharply.

Fig. 5 shows oscillograms of pulses from the detonation of open charges of ammonite No. 6 ZhV (129/10, 129/11) and from the detonation of the same charges surrounded by a casing of sand 10 mm thick (129/5, 129/6). As is evident from the figure, the sand coating sharply increases the radiation. The same picture is observed in the detonation of 62% dynamite. In this case the amplitude of the pulse increases more than 70 times. It is very interesting that in both cases the coating changes the polarity of the pulse.

The nature of the influence of the coating on the character of the radiation, in our opinion, consists of the following. As

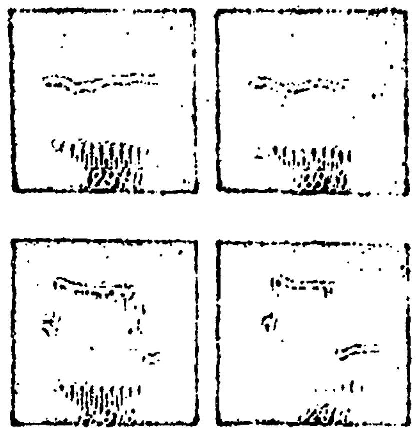

Fig. 5. Influence of a sand casing on the electromagnetic radiation from the explosion of ammonite No. 6ZhV.

is well known, any coating in which an explosive charge is placed exerts a substantial influence on the course of the detonation process and the subsequent expansion of the explosion products. As shown by the investigations of Belyayev (7), the influence of the casing is determined not so much by its strength as by its mass. In view of this, it would seem, incoherent coatings such as sand or water actually might prove to be sufficiently "rich", that is to exert a large influence on the expansion of the gaseous explosion products.

For this reason, in the right hand side of Eq. (4) $P = P(t)$ and $x = x(t)$ change, which means that the rate of increase of the dipole moment also changes (the curve $M = f(t)$ becomes more convex or concave). As a result, the magnitude of the signal received by the antenna, $A = f''(t)$ increases correspondingly. Therefore, the essence of the influence of the coating apparently consists chiefly of the fact that it changes the nature of the

expansion of the explosion products.

Corroboration of such an assumption is provided by the results of experiments involving the detonation of explosive charges in a mortar bore of diameter 55 mm and length 1.6 m.

The receiving system in these experiments was the same as in the case of the detonation of open charges. The distance from the antenna to the mortar section was taken to be 2.85 m, that is, the same as for the detonation of the open charges. As is well known, detonation in a mortar involves a certain barrier to the free escape of the explosion products. They behave as if they were retarded within the bore before being discharged to the atmosphere.

Fig. 6 shows an oscillogram obtained during the detonation of a cartridge of ammonite No. 6ZhV in a mortar bore. Comparing this oscillogram with the one in Fig. 5 which was photographed during the detonation of an open charge of the same explosive with the same parameters of the receiving system, it is not difficult to convince oneself of the following; first, the pulse is sharply increased by detonation in a mortar (the delineation is clearly visible in the oscillogram of Fig. 6); second, the radiation started approximately 300 msec after the detonation. This time agrees well with the time required for the detonation products to begin to escape from the mortar bore (8). Consequently, the radiation process for detonation in the mortar is associated with the expansion of the detonation products after

they have been discharged from the bore. The intensity and polarity of this radiation is completely determined by the parameters of the expanding explosion products. Since the mortar causes a fundamental change in the character of the expansion of these products, the change of the pulse upon detonation in the mortar may be considered as evidence for the influence of the nature of the expansion of the explosion products on the electromagnetic radiation arising therefrom.

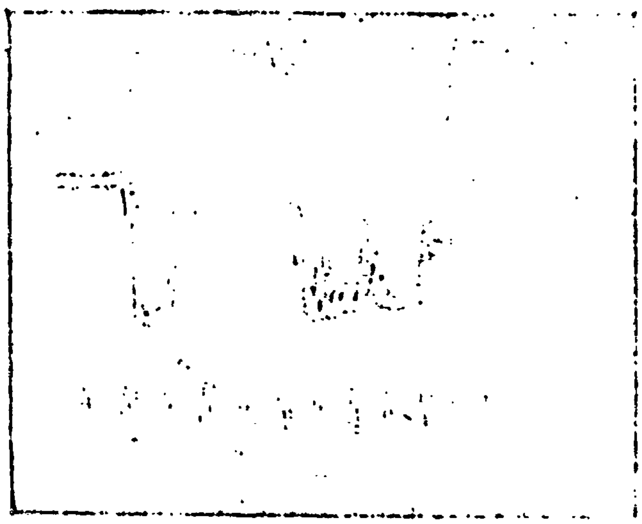

Fig. 6. Electromagnetic pulse from the detonation of a cartridge of ammonite No. 6ZhV in a mortar bore.

In concluding the analysis of the results of the experiments conducted, we pause to consider one other essential factor which requires explanation — the polarity of the radiation pulses. Kolsky (2) explains the different polarity of pulses from different explosives by the fact that in some cases the positive ions are more mobile than the negative ions, and vice versa. However, this fails to consider the fact that the carriers of negative

charge are chiefly electrons; that is, a separation of charges in the expanding explosion products which is differently polarized in different cases because of the different mobilities of the charge carriers is unlikely. Moreover, Kolsky was able to explain the different polarity of pulses from different explosives by such an interpretation only because of the very restricted volume of his experimental material. Actually, in a number of cases the pulse may change its polarity, for example during detonation in a mortar (see Fig. 6).

If this phenomenon is to be explained according to Kolsky's conception, then it is necessary to assume that the positive ions were more mobile than the negative ions at first, then became less mobile, then more mobile again, etc. This, of course, is absurd.

We propose a different explanation for the different polarities of pulses of radiation from different explosives.

The received signal is determined by the second derivative in the dipole moment equation, that is, in the final analysis, by the nature of the change of the dipole moment. If the rate of change of the dipole moment increases, the signal received by the antenna has positive polarity; in the opposite case it is negative. Such an explanation, in our opinion, completely agrees with the observed experimental data.

On the basis of the mechanism of electromagnetic radiation from explosions established by the work described above, it is

possible to contemplate several methods for its practical use, in particular for the determination of the effectiveness of stemming.

In the conduct of blasting work, stemming is usually placed between the charge and the mouth of the bore hole. Its purpose is to prevent the free escape of the explosion products from the bore hole in order that the energy stored in them may be used for the accomplishment of useful work in the destruction of a solid mass. Moreover, in mines containing dangerous amounts of gas or dust the use of stemming is a most important factor in guaranteeing the safety of blasting work.

It is quite obvious that, all other conditions being equal, the longer the stemming holds the detonation products inside the bore, the greater the fraction of the energy stored in them which will be expended in useful work for the destruction of a solid mass. For this reason, the length of time for which, under a given set of conditions, a given stemming retains the explosion products in the bore before they burst out may serve as a relative index for characterizing the effectiveness of the stemming. In comparing various types of stemming, those for which this time is greatest will be most effective.

As the investigations of Seleznev and Galadzhiy (8) showed, this time may serve simultaneously as a measure of the effectiveness of the stemming as a means for preventing the detonation of gas and dust.

Consequently, by determining the indicated time it is possible to make objective comparisons among various types of stemming and to select from the available assortment (for example, clay, sand of various coarseness and moisture content, various mixtures of clay and sand, various kinds of water stemming, ground slag, mixtures of ground slag with water, etc.) the one which is most suitable for a given set of conditions.

For the time being, the only means for determining the time of expulsion of the stemming out of the bore hole by the detonation products is high-speed cinematography. This method was used, for example, by Seleznev and Galadzhiy in the work referred to above. It must be mentioned that high-speed cinematography requires the expenditure of a great deal of effort and for extensive investigations may be used chiefly only at the surface in daylight.

This time may be determined considerably more simply and more objectively by making use of the electromagnetic radiation which is emitted during the detonation of an explosive charge.

In the course of investigating the electromagnetic processes accompanying the detonation of an explosive charge in a mortar, it was established that the primary part of the electromagnetic energy is liberated after the detonation products have been discharged from the bore. Thus there is a time interval after the beginning of the detonation during which the electromagnetic radiation is practically absent.

On the oscillograms (Fig. 7), this time is determined by the length of the initial region from the moment of triggering of the sweep (moment of detonation) to the beginning of the radiation process, which arises from the expansion of the explosion products into the atmosphere.

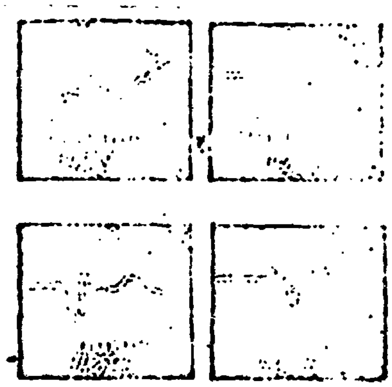

Fig. 7. Electromagnetic pulses from the detonation of explosive charges in a mortar with stemming of various lengths.

We will attempt to determine at which stage of this expansion the radiation begins. In reference (8) are reported data from high-speed cinematography of the process of expansion of explosion products issuing from a mortar bore without internal stemming. Having processed these data, it is possible to draw the conclusion that the "delivery rate" of the discharge of explosion products from the bore of the mortar in the initial stage of the process amounts to approximately 0.45 l/msec. Comparing these data with the data on the duration of the leading front of the pulse in the corresponding oscillograms (for example, 142/9; see Fig. 7), it can be concluded that the observed radiation may

occur during the discharge to the atmosphere of a total of about 10 l of gaseous explosion products; that is, at the very beginning of the expansion process.

The delay of the flow of explosion products out of the mortar bore into the atmosphere may be increased artificially by introducing stemming into the bore. When this is done, the region on the oscillogram between the moment of triggering of the sweep and the moment of appearance of the electromagnetic radiation is lengthened correspondingly. This may be illustrated by the oscillograms 142/9, 142/12, 142/13, and 142/18, reproduced in Fig. 7, which were obtained from the detonation of 200 g cartridges of ammonite in a mortar having a bore of length 1.6 m and diameter 55 mm. A schematic drawing of the experimental arrangement is shown in Fig. 8.

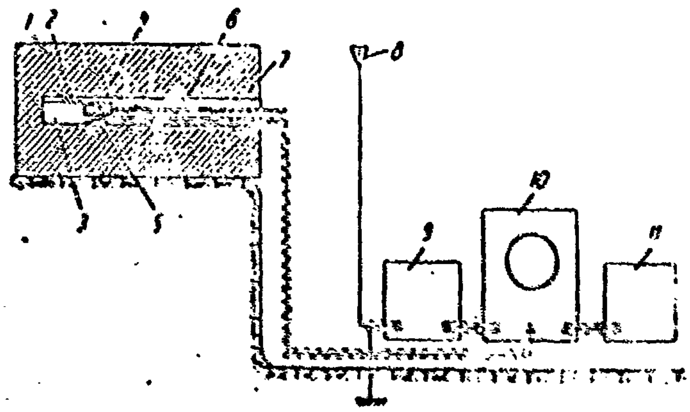

Fig. 8. Schematic drawing of the arrangement of experiments for the investigation of electromagnetic radiation from the detonation of explosive charges in a mortar with stemming.

1 - mortar; 2 - mortar bore; 3 - explosive cartridge; 4 - detonating cap; 5 - ionization gauge; 6 - fuse; 7 - stemming; 8 - antenna; 9 - cathode follower; 10 - oscillograph OK-17M; 11 - time mark generator.

The explosive cartridge 3 was placed in the bore 2 of the mortar 1. The receiving antenna 8 was a vertical piece of isolated conductor of length 2 m, placed at a distance of 2.85 m from the mortar section. The path of amplification of the signal received by the antenna consisted of the cathode follower 9 and the amplifier of the first channel of the OK-17M oscillograph. The time mark was supplied by the audio generator 11. The triggering of the sweep of the oscillograph was accomplished by means of the ionization gauge 5 inserted into the explosive cartridge. Flame detonation was used in the experiments, and the stemming was placed in the mouth of the mortar.

The oscillograms referred to above (see Fig. 7) were photographed during runs with clay stemming of lengths 5, 15, 30, and 45 cm, respectively. As is evident from the oscillograms, increasing the length of the stemming results in a corresponding increase of the duration of the initial region. Consequently, the length of time from the instant of detonation to the beginning of the outflow of explosion gases to the atmosphere increases.

In this way, the use of the electromagnetic radiation from the explosion makes it possible to determine the amount of time for which the stemming retains the explosion products inside the bore (blast hole).

In order to compare the data on the time of expulsion of the stemming, obtained by means of high-speed cinematography and

by the reception of electromagnetic radiation from the explosion, special experiments were conducted in which this time was determined in parallel by the two methods indicated. The arrangement for receiving the radiation was the same as in Fig. 8. The motion picture photography was performed with a type SKS-1M camera with a speed of 4000 frames per second.

The experiments were carried out with clay stemming of lengths 30 and 40 cm. The time of expulsion of the stemming, as determined by means of the recorded oscillograms, amounted to 3.3 and 4 msec, respectively. In the motion pictures this time is associated with a certain decrease of the density of the cloud flying out of the mortar. However, it does not seem possible to determine accurately the beginning of the discharge of gaseous explosion products to the atmosphere from the motion pictures, since it is difficult to distinguish the pulverized stemming from the opaque explosion products on the exposed frames.

Therefore, by using the electromagnetic radiation to determine the time of expulsion of the stemming, characterizing its effectiveness, this time can be determined not only more simply but also more accurately than by using high-speed cinematography.

Times of expulsion of various types of stemming from the mortar bore were determined by the scheme described above. The data obtained are represented by the curves in Fig. 9.

On the basis of these data the following statements can be made: 1) the time of expulsion of the stemming increases in a

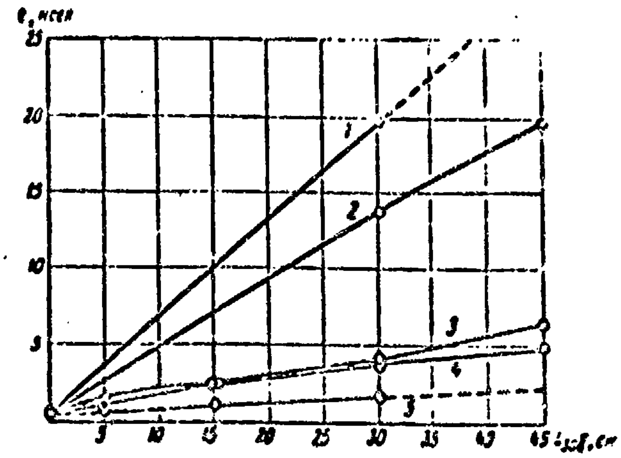

Fig. 9. Dependence of the time of expulsion of the stemming on its length for detonation in a mortar.

1 - sand A; 2 - sand B; 3 - water stemming in polyethylene hose; 4 - clay A; 5 - clay B.

regular fashion as its length increases; 2) the time of expulsion of stemming of the same length and of the same material is sufficiently reproducible in parallel experiments; 3) all other conditions being equal, the material of the stemming greatly influences the time required for its expulsion, and thus its effectiveness.

The experiments involving the detonation of explosive charges in a mortar approximate sufficiently well the conditions in a blast hole bored in solid rock; however, on the basis of the results obtained above it is still impossible to judge as to what electromagnetic phenomena will accompany an explosion in softer rock.

To answer this question, special experiments were conducted in the face of a header of an experimental mine of the Makayevka

Scientific Research Institute for Mine Safety (MakNII). The rock of this cut was described as very soft, broken by clay shale, and considerably weaker than coal. The experiments were conducted in blast holes of length 80 cm and with stemming lengths of 20–40 cm. A schematic drawing of the experiments is shown in Fig. 10.

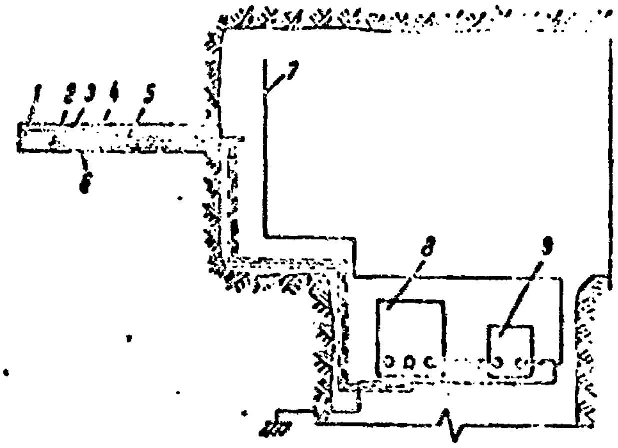

Fig. 10. Schematic drawing of experiments for the investigation of electromagnetic radiation from the detonation of explosive charges in blast holes with stemming.

1 – explosive cartridge; 2 – detonating cap; 3 – ionization gauge; 4 – oscillograph triggering cable; 5 – fuse; 6 – stemming; 7 – antenna; 8 – oscillograph OK-17M; 9 – cathode follower.

The oscillograms obtained from the experimental mine are analogous, in general, to those shown in Fig. 7. The results of the analysis of these oscillograms are presented in the table.

Having analyzed the data thus obtained, it is possible to make the following statements: 1) detonation in soft rock, as well as in a mortar, produces sufficiently clear and reproducible

Number of experiment	Stemming material	Length of stemming, cm	Time of expulsion of stemming, msec	Average time of expulsion of stemming, msec
154/3	Without stemming	--	1.0	--
152/4	Same	--	1.0	1.0
155/5	Clay	20	3.0	--
155/4	Same	20	6.0	4.5
152/1	Same	30	6.0	--
154/1	Same	30	7.0	--
155/1	Same	30	5.0	6.0
155/2	Sand	20	20.0	--
155.0	Same	20	20.0	20.0

(in the sense of the length of the initial region) electromagnetic pulses. These pulses are suitable for use in the determination of the effectiveness of the stemming; 2) the interference level in these experiments was considerably lower than for those carried out at the surface. For this reason, the initial regions of the pulses recorded in the experimental mine were practically completely flat; 3) the time of expulsion of the stemming from the blast holes bored into soft rock was greater than the corresponding time for detonation in the mortar.

Thus the experiments conducted in very soft rock and in the mortar can encompass a broad range of rock hardness. Since in all these cases electromagnetic pulses were received which were quite adequate for the determination of the time of expulsion of the stemming, it is possible to draw a conclusion about the possibility of the creation of a special apparatus, based on this

principle, for the determination of the effectiveness of stemming under industrial conditions.

The model of this apparatus built by us consists of a millitimer which measures the time interval between the receipt of two electrical pulses. The first pulse, which corresponds to the beginning of the detonation of the explosive cartridge, starts the millitimer, and the apparatus begins to record the time. This pulse is obtained by means of an ionization gauge. The second pulse is generated by the antenna upon receipt of the electromagnetic radiation which appears when the explosion products expand into free space. When this pulse is received, the apparatus records the time interval from the moment of detonation of the cartridge to the beginning of the expansion of the explosion products into the atmosphere, that is, the length of time for which the stemming has prevented the free discharge of the gases formed in the explosion.

The efficiency of the apparatus was tested on the artillery range by the detonation of charges of safety ammonite PZhV-20 in a mortar with sand stemming of length 30 cm. Several detonations were carried out. In these tests the apparatus gave times of delay of expulsion of the stemming which agreed well with the data obtained earlier.

It is quite clear that if various types of stemming are to be compared in this way, it is necessary that the conditions be comparable — that is, detonation of the same charges of the same

explosive in blast holes of the same length. Furthermore, the length of the stemming should also be the same in all blast holes, and the holes bored into the same rock. The latter requirement is necessary because of the fact that one type of stemming may be more effective in some kinds of rock and another type may be more effective in other kinds of rock.

Conclusions

1. The detonation of explosive charges gives rise to electromagnetic radiation whose parameters are determined by the properties of the explosive and the conditions of the detonation.

2. The electromagnetic radiation from the detonation of open charges of explosives is determined basically by the expansion of the ionized gaseous detonation products and can be explained on the basis of the kinetic molecular theory of gases by the nature of the motion of the ionized particles in the pressure field.

3. The nature of the electromagnetic radiation from the detonation of mixed industrial explosives is determined mainly by the following:

a) the presence in the explosive composition of easily ionized additives such as salts of alkali metals;

b) the presence in the explosive composition of combustible additives (sawdust, aluminum, etc.);

c) various factors preventing the free escape and expansion of the explosion products (the presence of casings, etc.).

4. The detonative components of mixed explosives do not exert any substantial influence on the character of the electromagnetic radiation of the charges.

5. The polarity of the pulses of radiation from various explosives is determined by the nature of the change of the dipole moment with time.

6. The characteristics of the electromagnetic radiation accompanying the detonation of explosive charges make it possible in a number of cases to use it as an effective means for conducting investigations which help to study more deeply the various processes involved in blasting, in particular the detonation.

7. When explosive charges are detonated in bore holes, the principal part of the electromagnetic radiation is emitted after the explosion products have been discharged to the atmosphere and is determined by the free expansion of these products.

8. The stemming, retarding the expansion of the explosion products, increases the time from the moment of detonation to the moment of escape of these products to the atmosphere. This time may be determined readily from the corresponding oscillograms.

9. For the same stemming, the time determined by detonation in bore holes in the mine was appreciably greater than by detonation in a mortar, due to the different degree of adhesion between

the stemming and the walls of the bore.

10. The time from the moment of detonation to the beginning of the discharge of the explosion products to the atmosphere, that is, to the moment of expulsion of the stemming, may serve as an indicator of the effectiveness of the latter.

11. A model apparatus for the evaluation of the effectiveness of stemming, based on this principle, was developed and tested.

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O Vozbuzhdenii i Razvitii Detonatsii v Geksogene

Author: A. V. Sokolov and Yu. N. Aksenov

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On the Initiation and Spread of Detonation in Hexogen

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Interdepartmental Commission on Blasting

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Up to the present time, the ideas about the mechanism of the initiation and propagation of detonation processes initiated by relatively weak impulses, for example by the transition from combustion of the explosive to detonation in a closed volume or by the action of an initiating shock wave attenuated by inert layers, have not been sufficiently clear.

This paper describes an investigation of the initiation and propagation of detonation in crystalline hexogen by burning in a closed volume and under the influence of an initiating shock wave produced externally. The general and special characteristics of the spreading of the detonation under these conditions are considered.

Experimental investigations. The object of the investigation was taken to be crystalline hexogen of five fractions: No. 1 - crystal dimensions of less than 0.2 mm; No. 2 - from

0.4 to 0.5 mm; No. 3 - from 1.25 to 2 mm; No. 4 - from 2.5 to 4 mm; No. 5 - from 5 to 7 mm.

The experiments were conducted in a laboratory assembly (Fig. 1) with granular charges, the density of which was approximately 1 g/cm^3 for fractions No. 1 - No. 4 and 0.85 g/cm^3 for fraction No. 5. In the investigation of the transition from burning to detonation, the charge was placed in a transparent plexiglass beaker, which was tightly sealed in a steel pipe closed at both ends and provided with apertures for photography. The tensile strength of the assembly under conditions of weakly dynamic loading amounted to approximately 1000 kg/cm^2.

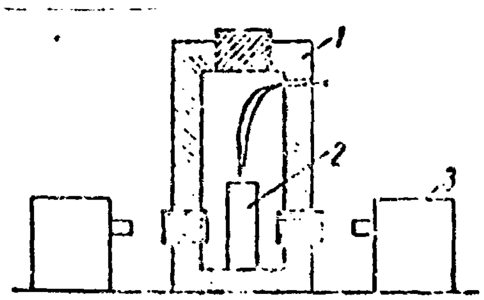

Fig. 1. Schematic drawing of laboratory assembly.
1 - bomb with windows; 2 - experimental assembly; 3 - ZhFR-1.

The charge was ignited by 0.5 g of black powder (Table 1).

The arrangement shown in Fig. 2 was used for the investigation of shock wave initiation of detonation.

The charge diameter in both cases was 20 mm and the length of the test section of the charge was 50 mm.

Table 1

A № фракции	B Минимальная скорость детонации D_{min}: C м/сек	D длина участка, мм	E Максимальная скорость детонации D_{max}: C м/сек	D длина участка, мм	F Особенности перехода D_{min} в D_{max}
1	1450	6	5770	40	Переход скачкообразный G
1	2540	6	6050	18	Плавный H
2	1760	14	5130	30	То же H
2	1900	6	3700	8	» H
2	—	—	6070	—	Начало детонации не попало на пленку I
3	1310	10	7590	6	В середине процесса $D = 3700$ м/сек J
3	2050	14	5600	27	Переход скачком K
3	1490	12	2630	16	То же K
4	1760	28	2900	10	Плавный H
4	2515	26	7350	10	То же H
5	1570	15	2350	25	» H
5	1150	25	—	—	—

Legend. A – Fraction No.; B – Minimum detonation velocity, D_{min}; C – m/sec; D – Length of zone, mm; E – Maximum detonation velocity, D_{max}; F – Nature of transition from D_{min} to D_{max}; G – Intermittent transition; H – Smooth; I – Beginning of detonation did not fall in the layer; J – At the midpoint of the process D = 3700 m/sec; K – Transition by jumps.

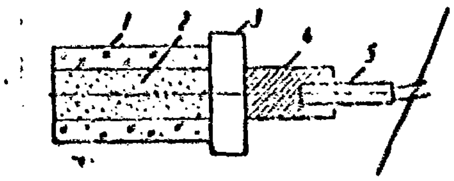

Fig. 2. Experimental arrangement for transmission of detonation.

1 – plexiglass beaker; 2 – passive charge; 3 – plastilin bearing disk; 4 – charge of TNT/hexogen 50/50; 5 – detonating cap.

In the shock wave detonation experiments, the activating

charge was cast TH (TNT-hexogen) 50/50, with a diameter of 20 mm and a height of 40 mm. The inert interlayer was a plastilin disk 3 to 30 mm thick and 50 mm in diameter.

The investigation was conducted by a photographic method, using a ZhFR-1. The speed of the film was varied in the range from 360 to 1780 m/sec.

In the flame ignition experiments the burning, in a certain region which we call the predetonation zone (h_{pred}), changes to detonation, which propagates with different velocities depending upon the dimensions of the hexogen crystals. The detonation wave originates at some distance from the flame front; that is, between the burning and detonation zones there is a non-luminous region which is apparently associated with unreacted material. In the majority of cases there are observed several velocities of detonation which change from one to another, either smoothly or in jumps. Fig. 3 shows the dependence of the length of the predetonation zone on the dimensions of the crystals, and the observed detonation velocities from the ignition of different hexogen fractions are presented in Table 1.

In the shock wave initiated detonation of a charge of hexogen, the detonation arises at a certain distance (h_{sw}) from the end (predetonation zone) and propagates with different velocities, which sometimes change smoothly or intermittently from one to another.

Typical photographs of the initiation and propagation of

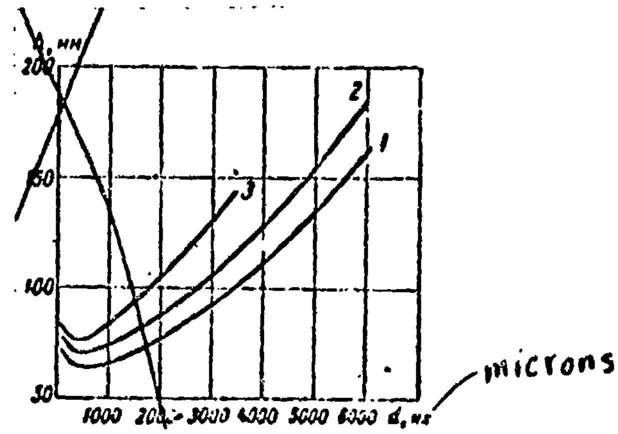

Fig. 3. Dependence of the length of the predetonation zone h on the dimensions of the grains of hexogen d under the conditions of transition from burning to detonation.

1 - curve corresponding to low detonation velocity; 2 - average detonation velocity; 3 - maximum detonation velocity.

detonation under the experimental conditions described above are reproduced in Figs. 4 and 5. Table 2 lists the numerical values of the measured velocities of detonation initiated by an attenuated shock wave. Fig. 6 shows the dependence of the predetonation zone on the thickness of the inert interlayer for various sizes of the grains of hexogen, and Fig. 7 shows the dependence of h_{sw} on the grain dimensions for a fixed (10 mm) thickness of the disk. Because of the fact that the burning zone did not fall within the visual field of the ZhFR in the experiments with hexogen, supplementary photographs of the process of transition from burning to detonation were obtained for another explosive. In Fig. 8 the accelerating burning, the layer of unreacted material between the flame front and the detonation wave originating in front of it, and also the detonation wave are clearly visible.

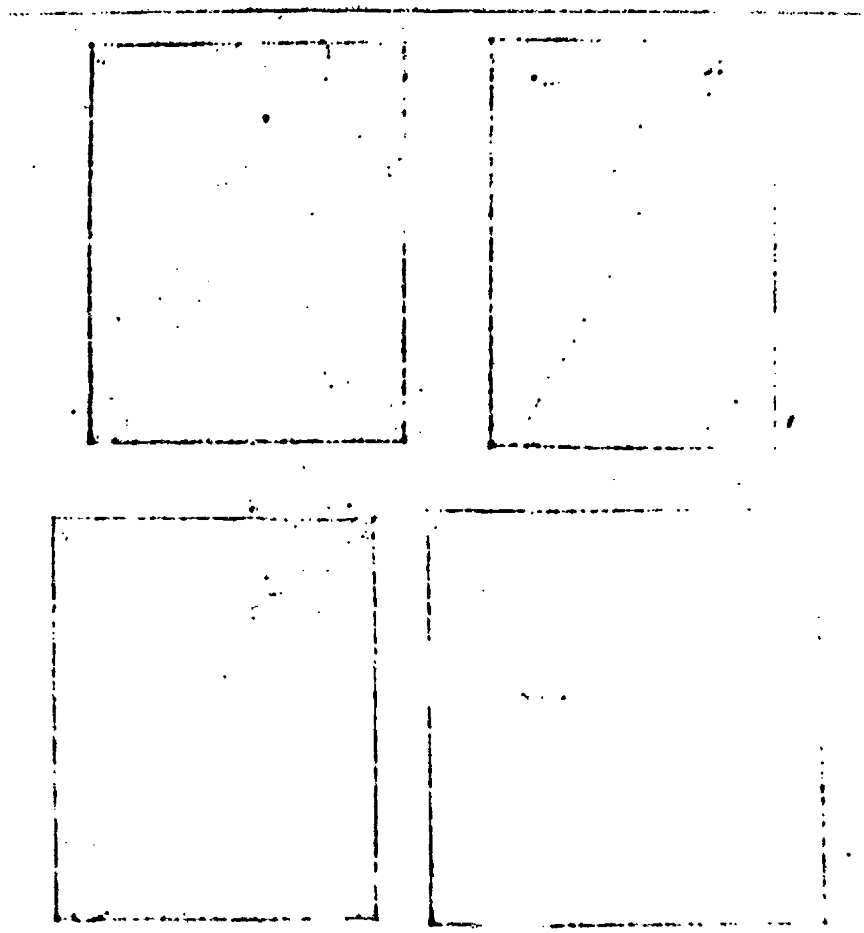

Fig. 4. Transition from burning to detonation.

a - fraction No. 2, height of charge 100 mm; b - fraction No. 1, height of charge 120 mm; c - fraction No. 3, height of charge 110 mm (photography was carried out through two isolated apertures); d - fraction No. 5, height of charge 180 mm.

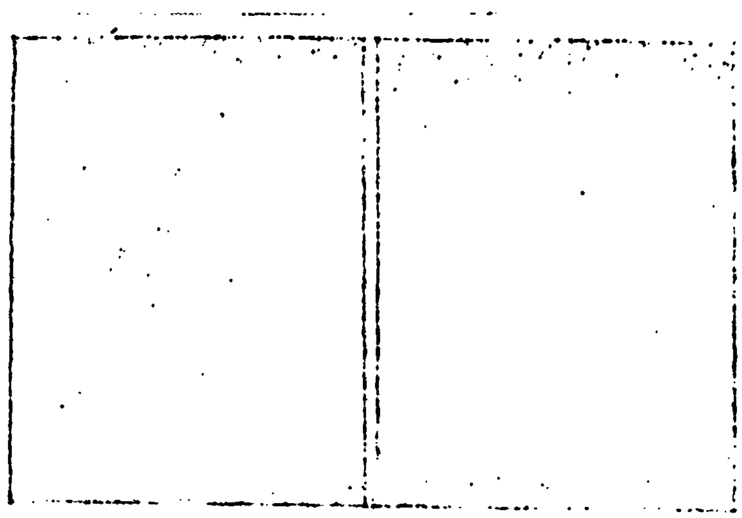

Fig. 5. Initiation of detonation by an externally produced shock wave.

a - fraction No. 3, thickness of plastilin disk 20 mm;
b - fraction No. 1, thickness of plastilin disk 10 mm.

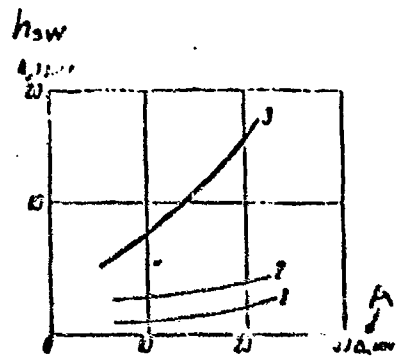

Fig. 6. Dependence of h_{sw} on the thickness of the inert interlayer for various grain sizes.

1 - fraction No. 1; 2 - fraction No. 2; 3 - fraction No. 4.

A - Δ = thickness of inert interlayer, mm.

Table 2

Fraction number	Thickness of inert interlayer	Characteristics of the development of the process
1	10	In a 20 mm zone D = 6250 m/sec; in the next 20 mm D - 5650 m/sec.
1	—	Initiated by KD
3	10	In a 12 mm zone D = 2600 m/sec; sudden transition to D = 5250 m/sec
3	10	D = 5500 m/sec
3	—	Initiated by KD, D = 6070m/sec
3	40	D = 1740 m/sec
4	10	In a 15 mm zone D = 2650 m/sec, then velocity decreases
4	10	In a 15 mm zone D = 2650 m/sec, then velocity decreases
4	20	D = 2470 m/sec
4	30	D = 1880 m/sec
5	10	In a 16 mm zone D = 4250 m/sec; at the end of the zone changes to D = 3200 m/sec, persisting for 15 mm
5	20	In a 10 mm zone D = 1540 m/sec, changing to D = 2540 m/sec for 15 mm

Translator's note — The seventh and eighth lines of the table were duplicated in the original.

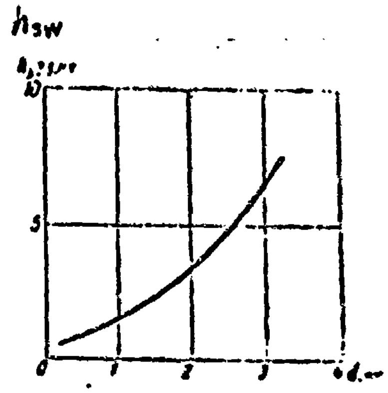

Fig. 7. Dependence of h_{sw} on the grain size d of hexogen with an inert interlayer 10 mm thick.

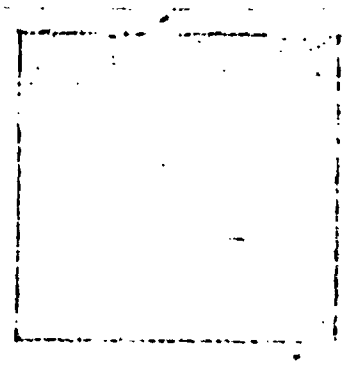

Fig. 8. Photorecord of the process of transition from burning to detonation.

A - end of charge; B - position of burning front at the instant detonation begins; C - position of origin of detonation; CD - detonation; CA - detonation wave.

On the transition from burning to detonation in a closed volume. The investigations carried out make it possible to describe, in general outline, the mechanism of the transition from burning to detonation as follows. After the ignition of the charge the hot combustion products which are formed exert a pressure on the charge, and the increase of pressure with time is accelerated because of the acceleration of the burning. As a

result, a compression wave whose profile changes with time as shown in Fig. 9 propagates through the charge. This is accompanied by a contraction of the material, depending on the steepness of the front, the density of the charge, and the dimensions of the particles.

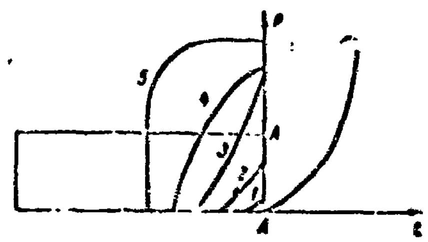

Fig. 9. Schematic drawing of the formation of a shock wave from a compression wave.

1-5 - successive positions and shapes of the wave at equal time intervals; AA - upper end of charge; P = f(t) - increase of pressure on the charge.

The steepness of the leading front of the compression wave increases because the forward regions of the wave propagate through the initial material with the velocity of sound, while the following regions propagate with a greater velocity through tightly compressed material. With a sufficiently rapid increase of the pressure on the charge, the steepness of the leading front may become so large that the compression wave becomes a shock wave, which causes detonation either immediately or after a certain induction period.

Maček (1) arrived at an analogous conclusion after investigating the transition from burning to detonation for cast pento-

lite and dynamite in strong steel tubes.

If the substance is gas-permeable, then the penetration of the hot products into the depth of the material plays a double role. On the one hand, it leads to an increase of the burning surface and correspondingly increases the rate of pressure increase in the burning layer, which is the source of the compression wave sent ahead to the fresh material. On the other hand, excessively high gas-permeability (due to a low density of the charge or to large particle dimensions) leads to rapid expulsion of the combustion products out of the combustion zone as they are formed. This decreases the rate of pressure increase, as a result of which the conditions for the formation of a steep pressure gradient along the charge are disrupted. As a result, either detonation does not arise or the length of the predetonation zone is substantially increased.

From Fig. 3 it is evident that there exists, in fact, an optimum particle dimension, or optimum gas-permeability, for which the length of the predetonation zone has its smallest value. With finer particles the rate of pressure increase is low because of the small surface, while it is low for coarser particles because of the increased flow of combustion products out of the combustion zone both into the depth of the charge and into the space above the charge. Moreover, the coarser the particles, apparently, the higher the velocity of sound in the granular charge; this also hampers the formation of a steep pressure gradient along the charge.

40

An analogous dependence of the length of the predetonation zone on the permeability of the charge was found by Griffits and Gruckok (2), working with granular and compressed charges of hexogen, tonite, tetryl, and octogen.

On the initiation of detonation by externally produced shock waves. From what was stated above it is still not clear whether detonation arises immediately upon formation of the shock wave or at a certain time after the passage of the wave through the material. Some light is cast on this question by experiments on the shock wave initiation of detonation, which show that for a given thickness of the inert interlayer (for which detonation is still initiated) detonation arises at a certain distance from the end of the charge. This distance depends on the thickness of the inert interlayer or on the intensity of the shock wave, and also on the dimensions of the grains of explosive. In none of the experiments was a burning zone or detonation wave recorded beyond the point of origin of the detonation.

The mechanisms which have been worked out make it possible to represent the process of initiation of detonation in granular charges by the action of attenuated shock waves in the following manner. If the shock wave is sufficiently weak or the dimensions of the particles are relatively large, then the initiation of detonation is retarded. In this case the shock wave has time to penetrate to a considerable depth (in our experiments, up to 18 mm, see Figs. 6-7). In so doing it creates an extended surface (pulverizes the material), establishes the seat of reaction, and

absorbs the material behind it. As a result, up to the moment directly preceding the origination of detonation the boundary between the inert interlayer and the passive charge migrates, according to approximate calculations, through a distance equal to about one-half h_{sw}. The layer of material enclosed between the upper end of the charge and the position of the shock wave appears to be greatly compressed. Extremely favorable conditions for the development of a detonative reaction are established, since the reaction is already initiated at all pores and defects and the substance appears to be drawn into these points.

After the contraction of the upper boundary of the charge and, possibly, the lateral surface, a relaxation wave follows. Therefore, it can be assumed that the most favorable conditions for the development of a fast reaction are realized at some distance from the new position of the upper boundary of the charge (approximately half the distance to the shock wave which arises ahead of it, or $\frac{1}{4}h_{sw}$).

It is possible that the reaction develops by a thermal detonation mechanism, since the particles are preheated by the shock wave. A subsidiary shock wave or series of waves is sent out through the substance from the fast reaction zone. It overtakes the primary wave after a short distance because of the fact that the intervening zone is compressed. At a distance h_{sw} from the initial upper boundary of the charge these waves combine and initiate detonation.

The reaction at the point of origin of the secondary wave apparently does not radiate sufficiently intensely, so that the region preceding the origin of detonation remains unreacting. Thus there is no sufficiently intensely radiating process in the entire region h_{sw}.

It can be assumed that in the transition from burning to detonation there is an analogous region h_{sw} which is a part of the predetonation zone under the conditions of burning in a closed volume; $h_{pred} = h_{sh} + h_{sw}$, where h_{sh} is the distance from the ignition point to the site of formation of the shock wave which produces the detonation. The special characteristic of h_{sw} in this process consists of the fact that it owes its origin to a longer and weaker wave. However, it is apparent that under conditions of burning in a closed volume the site of shock wave formation also lies above the point of origin of detonation, which can be seen on the film.

The following should be added to what has already been said. If detonation is initiated by a long and weak wave, then it is apparently possible to expect relatively slow burning with a subsequent transition to detonation by a mechanism analogous to that realized in the case of slow ignition of the substance in a solid casing. Such processes evidently can take place for substances which are highly sensitive to friction and which ignite quickly. The observed cases of ignition of ammonite by weak shock waves in the work of Dubnov and Romanov (3) point to such a possibility.

The predetonation zone h_{sw} is observed not only for powdered but also for slightly compressible solid substances, which, in our opinion, may be explained in the following way. On entering a compressed or cast charge the shock wave must cause the formation of a network of minute cracks, which may propagate with a greater velocity than the shock wave ahead of it. This network of cracks must substantially facilitate the development of a fast reaction. It is entirely possible that the most favorable conditions for the occurrence of a fast reaction are realized at a certain depth in the charge, in cracks which have not yet had time to diverge, as must have taken place at the very top of the charge. The explosive reaction which results initiates detonation at a short distance ahead of itself, just as in the case of a granular charge.

On velocities of detonation and transitions from detonation with one velocity to detonation with other velocities. Detonation with the maximum possible velocity for a given system, determined by the expression

$$D = \sqrt{Q(n^2 - 1)}.$$

is possible only if the potential energy of the explosive is completely liberated and converted to shock wave energy. This, in turn, is possible for sufficiently large charge diameters and a sufficiently powerful initiator. When these conditions are not fulfilled, regimes with decreased velocities arise. Andreev and Belyayev (1) report velocities of detonation of nitroglycerin falling in the range from 900 to 2000 m/sec, with D_{max} = 8500

m/sec. Detonation was initiated by weakened detonating caps. Cook (5) observed velocities from 1500 to 2500 m/sec in granular tetryl of various grain sizes, with small charge diameters (3-5 mm) and initiation by detonating caps. For hexogen under the same conditions he did not find velocities lower than 5500 m/sec.

Under the conditions of our experiments, the appearance of small velocities is to be expected, to begin with, because of the inadequacy of the initial pulse. Actually (see Tables 1 and 2) under the conditions of burning in a closed volume, as well as with initiation by an attenuated shock wave, detonation arises systematically with extremely small velocities (1300-1500 m/sec). In the first case, moreover, in none of the experiments was the maximum velocity recorded (for hexogen with a density of 1 g/cm^3, D_{max} = 6500 m/sec according to our data). As a rule the detonation which arises goes over to detonation with still higher velocity, either by a smooth transition or by jumps after a certain period of uniform expansion.

With initiation by externally produced shock waves such transitions are rarer and, as a rule, proceed by jumps.

In both cases, high detonation velocities are more easily established with finer particles.

The systematic transitions from smaller to greater velocities can be explained, apparently, by the "support" of the detonation wave from behind by the shock waves issuing out of the burning region.

The possibility of propagation of detonation with small velocities also depends upon the coarseness of the structure of the charge (small free surface), which substantially hampers the development of a fast reaction and the sustaining of the high detonation pressure necessary for propagation with a high velocity.

The absence of smooth transitions from low to higher velocities and the more rare intermittent transitions under the conditions of shock wave initiation can be explained by the absence of "support". Intermittent transitions occur because of the accumulation of additional energy sources which are suddenly liberated; for example, by means of a thermal explosion leading to the realization of a more powerful detonation process.

In conclusion we note that the regimes with small constant detonation velocities in certain bounded regions, observed under the conditions described above, evidently obey the basic rules of hydrodynamic theory. In particular, they predict the ratio of the bulk velocity of the substance u to the detonation velocity D, which is approximately ¼ (the magnitude of u was calculated from the luminescent track of the burning coarse hexogen particles in the detonation wave).

For hexogen with a particle size of 2 mm and detonation velocity of 6000 m/sec the width of the reaction zone was also calculated; it turned out to be equal to 35 mm.

The section "On the transition from burning to detonation"

was written jointly and the sections "On the initiation of detonation by externally produced shock waves" and "On velocities of detonation" were written by A. V. Sokolov.

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Classification: Unclassified

Title: The Problem of the Effect of the Degree of Dispersion of Sodium Chloride on the Properties of Safety Ammonites

K Voprosu o Vliyanii Dispersnosti Khloristogo Natriya na Svoystva Predokhranitel'nykh Ammonitov

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The Problem of the Effect of the Degree of Dispersion of Sodium Chloride on the Properties of Safety Ammonites

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MakNII /Makeyevka Scientific Research Institute for Mine Safety/

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The effect of the degree of pulverization of inert additives, in particular sodium chloride, on the properties of safety ammonites is well understood in general terms. Many safety ammonites are completely incapable of detonating if the inert salt they contain is finely ground, yet detonate without fail if the salt is introduced in the form of coarse crystals (1).

The dimensions of the inert salt particles have a twofold influence. The finer the particles, the more pronounced the safety properties of the explosive. However, excessive pulverization of the salt leads to an abrupt flegmatization of the explosive and decrease of the detonation susceptibility (2).

In the mechanism of ignition of a methane-air mixture, according to current ideas, an inert additive plays a triple role. In the first place, it decreases the detonation tempera-

ture; second, it inhibits the progress of the reaction of oxidation of methane which leads to its ignition; third, by promoting more complete decomposition of the explosive, it decreases the concentration of active intermediate compounds which contribute to the ignition of the methane-air mixture (3).

In view of what has been said above, the influence of an inert additive on one or another property of safety ammonite must depend not only on the degree of pulverization, but also on the relative amount of it in the explosive composition. In other words, the allowable dispersion of the inert additive must depend on its quantity in the explosive composition, and vice versa.

Experiments were conducted in order to evaluate the complex influence of the dispersion and specific content of the inert additive on the most important properties of the explosive.

Powdered ammonite No. 6 ZhV of standard composition was mixed with coarse or fine sodium chloride. The coarse salt used was a fraction which passed through a 2.8 sieve (inside dimension of mesh in mm) and remained on a 0.8 sieve. The fine salt passed through a 0.2 sieve and stayed on a 0.075 sieve.

Standard Trautsel bombs cast from soft lead were used in the efficiency determinations. The bombs gave a net expansion of 294 ± 2 cm^3 with 10 g of recrystallized trotyl. The effect of temperature was accounted for in carrying out the measure-

ments but the influence of the detonator (ED-8-56) was not considered.

Three series of experiments were conducted. Weighed portions of ammonite No. 6 ZhV of from 1 to 10 g were used in the first series. The explosive samples used in the second and third series were of the same weight (10 g) but contained from 10 to 90% coarse (second series of experiments) or fine (third series) sodium chloride. The averaged results of two experiments are presented in the graph of Fig. 1.

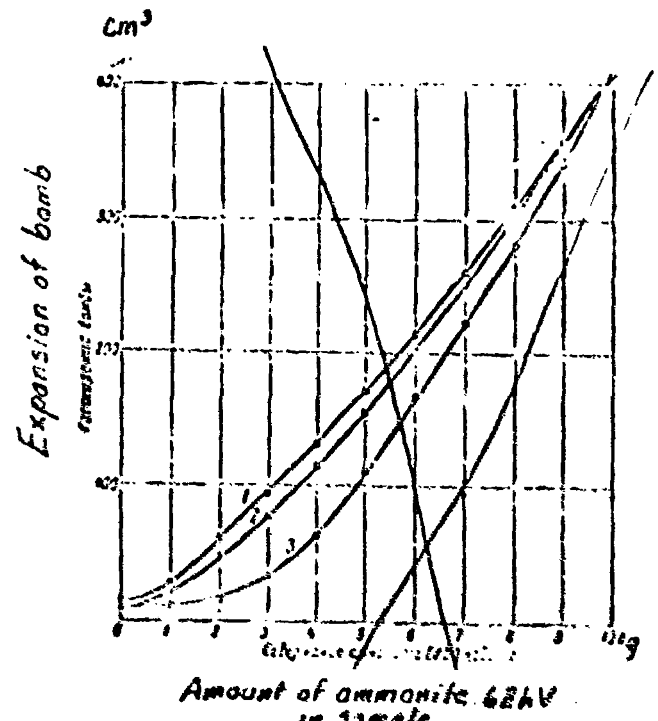

Fig. 1. Plot of the expansion of the Trautsel bomb from the explosion of ammonite.

1 - pure ammonite No. 6 ZhV; 2 - same mixed with coarsely dispersed NaCl; 3 - same mixed with finely dispersed NaCl.

As is evident from Fig. 1 (curve 1), the expansion of the bomb is not directly proportional to the weight of the explosive

sample, as is well known. However, on a certain portion of the curve (from 5 to 10 g ammonite No. 6 ZhV) the observed relationship is practically linear. From this it is possible to draw the important preliminary conclusion that, for portions of explosive of equal weight, the efficiency (expansion of the bomb) is practically independent of the magnitude of the initial volume of the charge (in the range under consideration).[1] This

1 -- The author's assertion that the expansion of the bomb is independent of the volume of the charge V cannot be accepted as conclusive, since from the experiment (linear portion of the curve) it follows only that $\left(\frac{\partial\phi}{\partial M}\right)V + \phi\left(\frac{\partial\phi}{\partial V}\right)M$ = const in the given region, but it does not follow that $\left(\frac{\partial\phi}{\partial V}\right)M = 0$. -- Editor's note.

means that the curves can be compared at points corresponding to equal quantities of ammonite No. 6 ZhV, independently of the differences in the volumes of the charges. Such a comparison shows that if the explosive contains 10% or less of coarse sodium chloride its efficiency is practically equal to the efficiency of the active portion of the charge. From this it follows that coarse sodium chloride in quantities up to 10% evidently may not play the first of the above-mentioned three roles in the mechanism of ignition of methane-air mixtures (lowering of detonation temperature). With coarse sodium chloride contents of up to 20% (the point corresponding to 8 g of ammonite No. 6 ZhV) the efficiency of the explosive does not

differ very much from the efficiency of its active part. If the coarse sodium chloride content of the explosive is increased further, the efficiency of the charge differs more greatly from the efficiency of its active part (the decrease of the temperature of the explosion products due to absorption of heat by particles of the inert additive begins to take effect).

Increasing the content of fine sodium chloride in the explosive leads to a sharper decrease of efficiency (curve 3), which attests to the more rapid decrease of the detonation temperature because of the increased heat exchange between the explosion products and the inert additive particles.

The data quoted above indicate that the theoretical calculation of the detonation temperature of safety explosives, based on the assumption of equilibrium heat exchange between the explosion products and the particles of "inert" additive, gives results that are clearly too low, and the more so the coarser these particles and the smaller their content in the explosive composition.

From the graph (see Fig. 1) it is possible to define equivalent charges on the basis of efficiency. For example, to obtain an expansion of the bomb of 200 cm^3 it is necessary to take a 5.7 g portion of ammonite No. 6 ZhV. In order to obtain the same expansion from a mixture of ammonite No. 6 ZhV with sodium chloride, it is necessary to take 5.9 g of ammonite and 4.1 g of coarse salt (41%) or 6.5 g of ammonite and 3.4 g of

fine salt (34%). To obtain the same efficiency, for example 304 cm^3, it is necessary to use an ammonite No. 6 ZhV composition containing 20% coarse salt or 16% fine salt.

Using mixtures of the same samples of ammonite No. 6 ZhV with sodium chloride of the indicated fractions, experiments were conducted to determine the brisance on lead columns, the velocity of detonation, and the transmittal of detonation in the open air. Cartridges of diameter 32 mm with explosive density of 1 g/cm^3 were used in the last two experiments.

The safety properties of the explosives were determined by detonating open charges of weight 50 g (with cartridge diameter of 32 mm) in the chamber of an experimental drift mine filled with a 9.5% mixture of methane in air. The frequency of ignition of the mixture served as a criterion for evaluating the explosive.

The results of the experiments are shown in Figs. 2-5, from which it is evident that the percentage of sodium chloride in the explosive composition and its fineness exert a strong influence on the basic properties of a safety explosive. At the same time, the influence of one factor may be compensated by the influence of the other. Thus the same brisance, for example 14 mm, is obtained from ammonite No. 6 ZhV containing either 20% coarse or 10% fine salt. The same detonation velocity, for example 3500 m/sec, is obtained from ammonite No. 6 ZhV containing either 17% coarse or 7.5% fine salt. A detonation trans-

mittal of 5 cm is obtained from ammonite No. 6 ZhV containing either 20% coarse or 5% fine salt. Similarly, in order to guarantee the same frequency of ignition of the methane-air mixture, say 50%, it is necessary to add about 30% coarse or about 11% fine salt to the ammonite No. 6 ZhV.

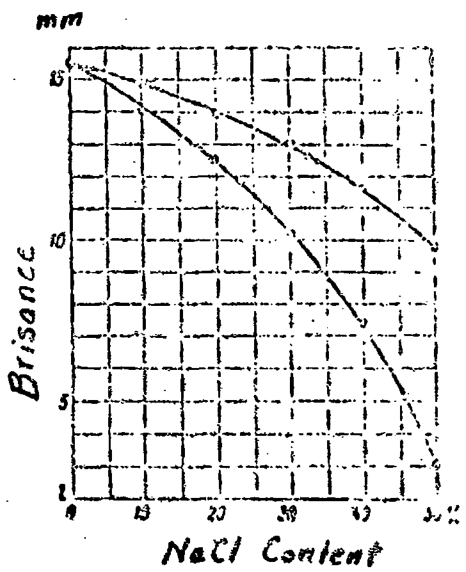

Fig. 2. Dependence of the amount of compression of a lead column on the NaCl content of ammonite.

1 - coarsely dispersed NaCl; 2 - finely dispersed NaCl.

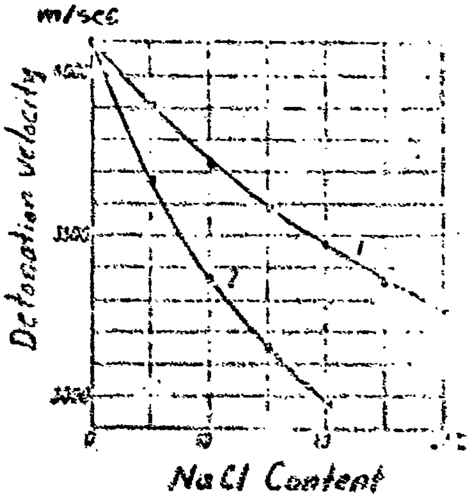

Fig. 3. Dependence of the detonation velocity on the NaCl content of ammonite.

1 - coarsely dispersed NaCl; 2 - finely dispersed NaCl.

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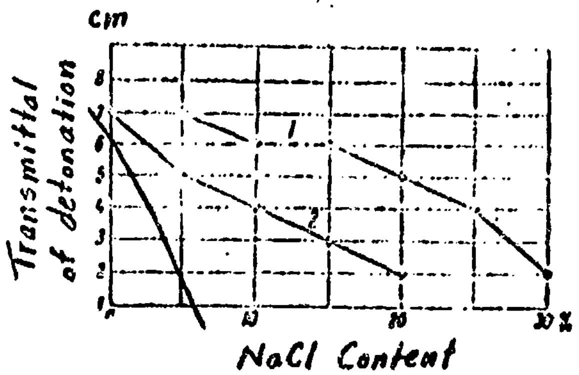

Fig. 4. Dependence of the transmittal of detonation on the NaCl content of ammonite.

1 - coarsely dispersed NaCl; 2 - finely dispersed NaCl.

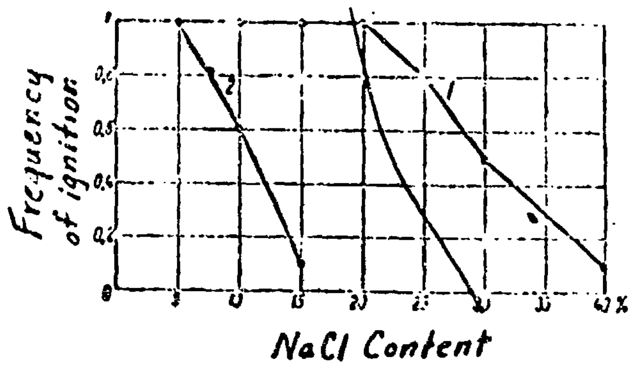

Fig. 5. Dependence of the frequency of ignition of a methane-air mixture on the NaCl content of ammonite.

1 - coarsely dispersed NaCl; 2 - finely dispersed NaCl.

In the current production of safety ammonites, as a rule, they use coarsely dispersed sodium chloride with crystal sizes of approximately 1 to 3 mm, amounting to as much as 20% of the explosive composition. With such a relatively large salt content, increasing its degree of dispersion results in a decrease of the detonative characteristics of the explosive. In order to avoid this it is necessary to increase the granulometric requirements for the salt, and thus to complicate the technology

of the explosive production. As shown by the experiments described above, it is possible to prepare explosives in which the coarse salt is replaced by fine salt. By selecting the equivalent quantity of fine salt, it is possible to preserve a given level of safety properties and detonative capability of the explosive and at the same time to obtain a gain in efficiency, since considerably less of the fine salt is required. Fine grinding of the salt can be guaranteed by the simultaneous charging of the primary components of the mixture into the apparatus at the stage of the process in which the explosive is ground and mixed.

Conclusions

1. With an increase of the sodium chloride content of ammonite, the detonative and safety properties change more sharply in the case of finely ground salt.

Finely dispersed salt in amounts greater than 10% decreases the efficiency of the explosive in greater than direct proportionality to its quantity in the ammonite. Coarsely dispersed salt in amounts up to 20% decreases the efficiency of the ammonite according to the relative amount of the salt. This implies, apparently, that the temperature of the explosion products is not lowered substantially by the introduction of coarsely dispersed salt in the indicated amounts. The safety properties of such explosives are guaranteed, in all probability, chiefly

because of the negative catalytic action of sodium chloride on the oxidation of methane and the positive catalytic effect on the decomposition of the explosive.

2. The principal properties of safety ammonite are not impaired if coarsely dispersed sodium chloride is replaced by finely dispersed sodium chloride, provided that the amount of salt in the explosive is decreased correspondingly.

Literature

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